Recent Improvements in IERS Rapid Service/Prediction Center Products

N. STAMATAKOS[1], B. LUZUM[2], B. STETZLER[3], W. WOODEN[4], E. SCHULTZ[5]

[1 2 3 4 5] USNO
3450 Massachusetts Avenue, N. W.
Washington, D. C. 20392

[1] e-mail: Stamatakos.Nick@usno.navy.mil [2] e-mail: Brian.Luzum@.usno.navy.mil
[3] e-mail: Stetzler.Beth@.usno.navy.mil [4] e-mail: Wooden.William@usno.navy.mil
[5] e-mail: Schultz.Emily@usno.navy.mil

ABSTRACT. The International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center (RS/PC) has made several improvements to its combination and prediction products since the last Journées conference in 2007. These improvements are due to the inclusion of new input data sources as well as modifications to the combination and prediction algorithms. These changes and their impact on the users of the RS/PC data are presented.

1. INTRODUCTION

The IERS RS/PC provides daily Earth Orientation Parameters (EOP) which are used in determining the terrestrial to celestial transformation matrix. These EOP values include polar motion, UT1-UTC, and celestial pole offsets, which can be obtained from the Bulletin A or finals data series located at http://maia.usno.navy.mil. After an overview of the RS/PC solution is given, a review of the UTGPS (Universal Time-like quantity using Global Position System data) processing and its usage in the combination and prediction software is presented. Recent and future improvements to the combination and prediction process include a new UTGPS solution with an improved filtering process, an increase in the number of Atmospheric Angular Momentum (AAM) forecast days, and Rapid Turnaround electronic Very Long Baseline Interferometry (RT e-VLBI) observations.

2. OVERVIEW OF EOP RS/PC SOLUTION

The daily EOP combination and prediction solution (finals.daily) is produced at approximately 1700 UTC each day; the weekly version (Bulletin A) is produced on Thursday at approximately 1700 UTC. Data from VLBI, Global Positioning System (GPS), Satellite Laser Ranging (SLR), and AAM are used in these solutions. Observations from the past are combined with appropriate weighting factors and used, along with AAM forecast data, to predict EOP values into the future. It is estimated there are 600 users who receive IERS RS/PC data each week, and roughly 40000 ftp downloads per month. Most uses of the data are for practical, non-research purposes with many users — 85 to 90 % — having limited technical skills. Details on the inputs, processes, and results of the RS/PC solution can be found at Stamatakos et al., (2008).

3. REVIEW OF AND FUTURE DEVELOPMENTS IN UTGPS PROCESSING

Each day near 1700 UTC, just after the IGS Rapid orbits are determined, a UT1-like quantity, called UTGPS, is generated. It is an estimate of UT1 at noon UTC for the previous day (Tracey et al., 2008). Not only is the UTGPS solution an accurate addition to the combination solution after the last VLBI intensives are generally available, but the last UTGPS solution also provides a good starting point for UT1 predictions.

The following is a conceptual description of the determination of UTGPS. Suppose one obtains orbit positions for GPS satellites in both celestial and terrestial coordinates. If one also had a good estimate of the parameters for the tranformation from terrestrial to celestial coordinates, except for the UT1 contribution, then one could solve for UT1 of the Earth.

On the most recent day with VLBI observations, the Earth orientation parameters are very accurately known. The GPS positions in the IGS Rapid orbit file for that day can then be transformed from the terrestrial positions (at 15 minute intervals) for any satellite in the file to celestial coordinates. An integrated orbit (called a starting orbit) is then fit to these inertial positions. The integrated orbits always take known Earth and Solar System gravitational forces into account, and also use a Solar Radiation Force (SRF) model. The SRF model for the satellite gives very accurate perturbations for the orbit plane, as a function of Sun angle from the satellite orbit plane, since it is based on the orbit perturbations observed in previous years.

On any succeeding day near 17:00 UTC, the IGS Rapid orbits file for the preceding day becomes available. Using any reasonable a priori estimate (or prediction) of Earth orientation parameters for that day, the terrestrial positions for the satellite from the file are transformed to obtain approximate observed positions in the celestial frame. The starting orbit is then integrated to the same 24 hour time span to give accurate predicted positions in celestial coordinates at the observed position times. The position residual vectors between the observed and predicted positions are determined; in particular, the component of the residual vectors along the predicted orbit normal is computed. Lastly, the correction to the a priori UT1 value which minimizes this component is found. This correction more accurately positions the Earth in the celestial frame. This correction applied to the a priori UT1 value at 12 hr UTC gives an estimate of the true UT1 value, assuming that the modeling errors in the integrated GPS orbits are smaller than the unpredictable variations in UT1 from day to day. The above procedure is applied to multiple GPS satellites, and the median of the determined UT1 values is UTGPS. For more details the reader is referred to (Kammeyer, 2000) and (Tracey et al., 2008).

After the UTGPS estimate is made for noon UTC, it must be processed further before using it in the EOP combination software. Figure 1 contains a flowchart of the anticipated high-pass filtering process. A cubic spline is fit to several weeks of UTGPS data. VLBI data, which have had systematic corrections applied, are then subtracted from the UTGPS cubic spline. The resulting residuals are low-pass filtered and then sorted into two groups — those before (inclusive) and those after the last VLBI epoch. Currently, an auto-regressive fit is made for those points after the last VLBI epoch and then the low pass filtered residuals are subtracted from both groups. In the near future, smoothing and a linear prediction fit will be applied to the data after the last VLBI epoch, which results in improved UTPGS accuracy after the last VLBI epoch when compared to the auto-regression prediction. Finally, the low pass residuals will be subtracted from both groups.

Residuals, created by subtracting the Bulletin A UT1 data from the unfiltered UTGPS values, are shown in Figure 2(a) using both the current and new UTGPS (which is described in the next paragraph). The new UTGPS has less noise than the current version. (Note, the new UTGPS was not run continously; it was restarted at MJD 53720, and that is the reason for the jump back to a residual of 0.0 at MJD 53720.) Figure 2(b) contains the residuals created by subtracting the Bulletin A UT1 data from the calibrated filtered UTGPS data that are used in the combination process. The 1-σ residuals computed using the current UTGPS data are 18 μsec; whereas, with the new UTGPS data, the 1-σ error is reduced to 12 μsec.

A new UTGPS solution has been developed. It uses between 15 and 25 satellites, as opposed to approximately 10 for the current UTGPS solution. Better solar force modeling has been incorporated; the JGM3 gravity model (degree 12, order 12) is still used and provides sufficient accuracy. The initial results are encouraging — there is significant improvement in the UT1 estimates. Given the better solution at the end of the combination, the UT1 predictions should also improve since there is a more accurate starting point for them. The quality of the new UTGPS solution is being monitored. It is anticipated that the new UTGPS will be incorporated into the operational procedures by early 2009.

4. REVIEW OF AAM ESTIMATION USED IN THE RS / PC SOLUTION

The flowchart in Figure 3(a) and also Figure 4 of Stamatakos et al. (2008) illustrates the AAM estimation process, except for the change in forecast length from 5 to 7.5 days. A detailed explanation of the flowcharts can be found in Stamatakos et al. (2008). The additional AAM forecast data from National Oceanographic and Atmospheric Administration (NOAA) and U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS), was added to the EOP combination and prediction software beginning on October 4, 2007. The resulting prediction accuracy has improved beyond the 5-day range since this change was implemented. Figure 3(b) illustrates the improvement in the prediction accuracy during the first 10-month period when the AAM forecasts were increased from 5 to 7.5 days, with the accuracy increasing by approximately 15% at 7 days.

5. RAPID TURNAROUND (RT) e-VLBI INTENSIVES

The RT e-VLBI intensives are observed and processed more recently than the IGS Ultra orbit observations. An analysis of the effect of the RT e-VLBI intensives on the RS/PC combination and prediction of UT1 was started on September 30, 2007, and has continued to the present. Only the last day of the combination and the 1-day prediction were analyzed. There were a limited number of solutions with the RT e-VLBI. As listed in Figure 4(a), there was a noticeable improvement in the combination solution — roughly a factor-of-2 improvement using the RT e-VLBI over the standard solution. The prediction improvement was smaller — there was only an improvement of 20% over the standard solution.

8. FUTURE DIRECTIONS

Additional monitoring of AAM residuals and statistics, for both analysis and forecast data, is being planned. Figure 4(b) contains an example of the AAM residual plot statistics being implemented at the RS / PC for monitoring of AAM analysis data. Using the European Centre for Medium-Range Weather Forecasting (ECMWF) series in addition to the NOGAPS and NCEP data, is also being investigated.

9. REFERENCES

Kammeyer, P. (2000), "A UT1—like Quantity from Analysis of GPS Orbit Planes", Celestial Mechanics and Dynamical Astronomy 77: pp. 241-272, 2000.

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Tracey, J., Kammeyer, P., Stamatakos, N., (2008) "Usage of the UT1-like Quantity at the USNO", International GNSS Service, Analysis Center Workshop, 2-6 June 2008, Miami Beach, Florida, USA.

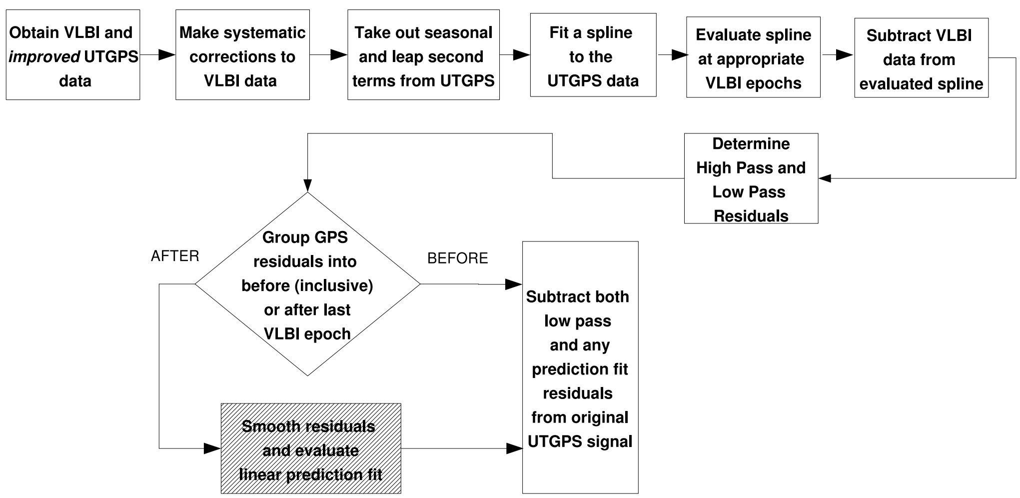

Figure 1: Future High Pass Filtering Flowchart for UTGPS

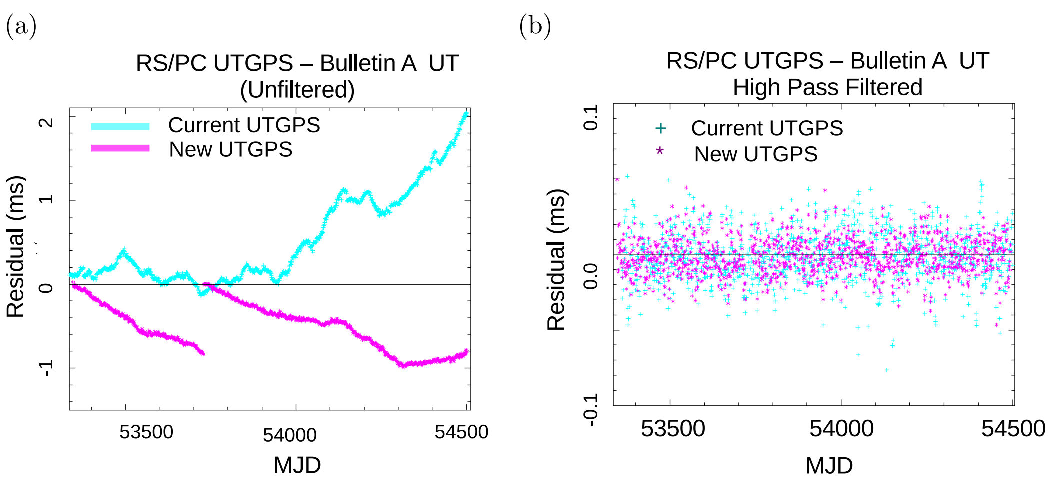

Figure 2: (a) Residuals of Unfiltered UTGPS and (b) Residuals of High-pass UTGPS

(a) (b)

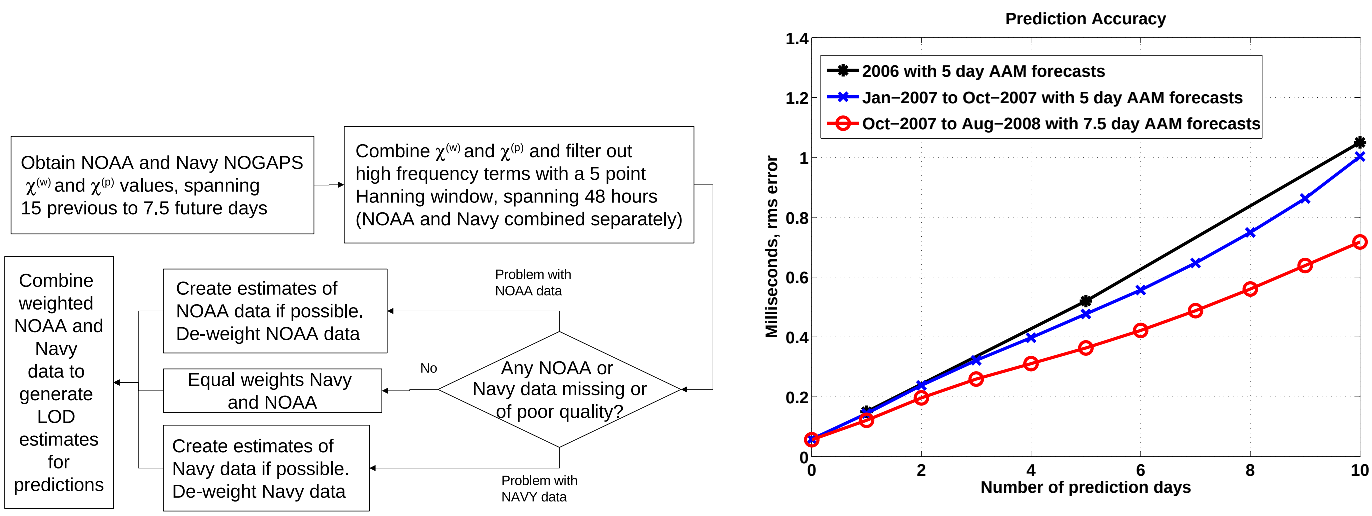

Figure 3: (a) Processing of AAM data before using it in the combination and prediction process, and (b) Recent Improvements in EOP Prediction Results before and after AAM forecast data was extended from 5 to 7.5 days

(a)

Intensive	Solution	Number of points	(μsec) Estimated Error
Rapid	Combination	21	23
Rapid	Prediction	21	99
Standard	Combination	303	57
Standard	Prediction	303	123

(b)

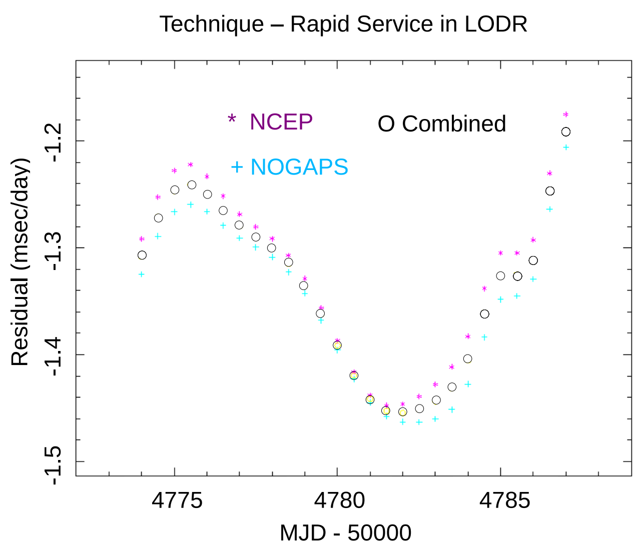

Figure 4: (a) Preliminary Results from the Rapid e-VLBI Analysis, and (b) AAM minus LODR daily diagnostic plot